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Installation of deflector in Colider Dam to minimize the percentual of total dissolved gases

Construção do defletor na UHE Colíder para minimizar o percentual total de gases dissolvidos (TDG)

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ABSTRACT

During voluntary or involuntary spills, the total dissolved gas (TDG) may increase with potential of causing gas bubble disease (GBD) in affected fish. Bubbles entrained during spill events in Colider are transported by plunging jets to deep, high pressure, regions in the tailrace where dissolution is enhanced increasing TDG concentrations. The most common alternative to minimize TDG supersaturation downstream of hydropower dams is to install deflectors on the spillway face. In order to reduce TDG levels downstream of the Colider's spillway, Copel retrofitted the four spillway bays with deflectors, finalizing the construction in November 2021. The design of the deflectors were assisted with two studies. The first study comprised the development of a physical model in 1:60 scale, and other study was a numerical model based on the open-source toolbox OpenFoam.

Keywords: Total dissolved gas (TDG); Deflector in spillway; Physical model.

RESUMO

Durante vertimentos voluntários e involuntários o total de gás dissolvido (TDG) aumenta e pode causar a doença da bolha em peixes. Elevada concentração de TDG em usinas ocorrem quando as bolhas de ar são carregadas pelo fluxo de água e transportadas para o fundo da bacia, que devido a alta pressão faz com que as bolhas sejam dissolvidas. Uma alternativa para reduzir a concentração de TDG é construir defletores no vertedor. Na UHE Colíder foram construídos quatro defletores no vertedor, uma em cada vão. Para auxiliar no projeto deste defletor foram realizados dois estudos: o primeiro em modelo hidráulico reduzido e no segundo foi elaborada uma modelagem matemática utilizando o OpenFoam.

Palavras-chave: Total de gases dissolvidos (TDG); Defletor em vertedouros; Modelo físico.

INTRODUCTION

During voluntary or involuntary spills, the total dissolved gas (TDG) may increase which can induce gas bubble disease (GBD) in fish. High dissolved gas concentrations occur when the aerated flow passes through zones of high pressure in a spillway plunge pool (Hibbs & Gulliver, 1997). The effect of TDG supersaturation is complex and depends on the TDG levels, exposure time and the species of fish (Weitkamp & Katz, 1980). Bubbles may form under the skin, mouth, gills, fins, and eyeballs of affected fish (Canadian Council of Ministers of the Environment, 1999).

Elevated TDG concentrations in hydropower dams occur due to dissolution of bubbles entrained during spill events at deep-high pressure regions in the tailrace (Geldert et al., 1998). The amount of bubbles at depth depends on the spillway jet regime and bubble size, the latest is a function of air entrainment processes in the plunging region, breakup, and coalescence (Politano et al., 2012).

One alternative to minimize TDG supersaturation is to install deflectors on the spillway face to redirect the regular plunging flow to surface jets tangential to the free surface (Politano et al., 2016). This structure was used or is being evaluated in others hydropower plants (HPP) such as Hells Canyon Dam (Politano et al., 2016); McNary Dam (Politano et al., 2015; Wang et al., 2018); Wanapum Dam (Hadjerioua et al., 2014); Brownlee Dam (Myers & Parkinson, 2003) and Yacyretá HPP (Bacchiega & Fattor, 2014).

Colíder HPP is in the Teles Pires River in the northern region of Mato Grosso, Brazil. The dam, built and operated by Copel Generation and Transmission S.A., has four spillway bays. Bubbles entrained during spill events in Colíder dissolve air into the water increasing TDG concentration. In order to decrease the TDG levels downstream of the Colider's spillway, and thus prevent potential gas bubble disease in fish, Copel installed deflectors in the four spillway bays. The design of the deflectors was assisted with two studies. The first study was a 1:60 scale physical model developed by Lactec, and the other study was a numerical model based on the open-source toolbox OpenFoam developed by IIHR-Hydroscience and Engineering at the University of Iowa and the US Army Engineer Research and Development Center. The design of deflectors was guided by the observed jet regimes in the physical model. However, since bubbles are not scaled in the laboratory, the TDG generation, with and without deflectors, was evaluated using a computational fluid dynamics (CFD) model. Various TDG modeling approaches are found in the literature, including the use of analytical correlations (Hibbs & Gulliver, 1997; Orlins & Gulliver, 2000; Kamal et al., 2020) and CFD. The first methodology is efficient but is limited to the conditions for which the parameters are determined and cannot be used for designing new structures. Recent advances in computational power have allowed the use of mechanistic models to assess the performance of spillway deflectors (Politano et al., 2009, 2012, 2014; Li et al., 2022). In this study, a comprehensive three-phase flow CFD model was utilized. This approach allows the simultaneous prediction of the free surface, the gas volume fraction of bubbles in the liquid phase, and TDG.

This paper briefly describes the developed models and evaluates the effectiveness of the constructed deflector. The approach used in this study integrates physical and numerical models and involves continuous monitoring of TDG near the dam to assess TDG production before and after deflector installation, To the best of the authors' knowledge, the methodology employed in this study has not been previously published. The results and approach presented in this paper are expected to be useful to engineers, project managers and ecologists responsible for reducing TDG in other hydropower installations.

COLÍDER DAM

Colíder HPP is an earthfill dam located at Teles Pires River in the northern region of Mato Grosso, Brazil. The dam is 1,526 m long and has a rated power production of 300 megawatts. The spillway has four bays controlled with radial gates with 16.7m high and 12 m wide, and it was designed for a 10,000-year flood of 6,935 m^3/s. Colider started filling the reservoir in February 2017. The dam operation began in 2019 with three Kaplan turbines, built and operated by Copel Generation and Transmission S.A. (Figure 1).

The reservoir normal water level is 272.0 m. The spillway crest is located at elevation 255.3 m. The energy dissipation structure is a hydraulic jump type stilling basin. Figure 2 show the spillway cross-section.

PHYSICAL MODEL

According to the literature, four typical jet regimes may occur due to the combination of the operational settings of the spillway and tailwater elevation: 1) plunging flow, 2) skimming flow, 3) undular jet and 4) surface jump. Plunging flow is undesirable since spillway jets plunge deep into the stilling basin increasing TDG levels.

The spillway model scale was 1:60, reproduced the crest, piers, radial gates, and the downstream bridge located at the downstream limits of piers. Since gravitational forces are the predominant forces acting on the system, the reduced scale model was constructed and operated based on Froude similarity.

Deflectors are designed to prevent the plunging flow that transports bubbles to high-pressure regions where dissolution is enhanced. The spillway flow regime depends on the spillway flowrate, tailwater elevation (TWE), and deflector characteristics such as length, curvature radius, and elevation on the spillway face.

Figure 1. Colíder HPP.

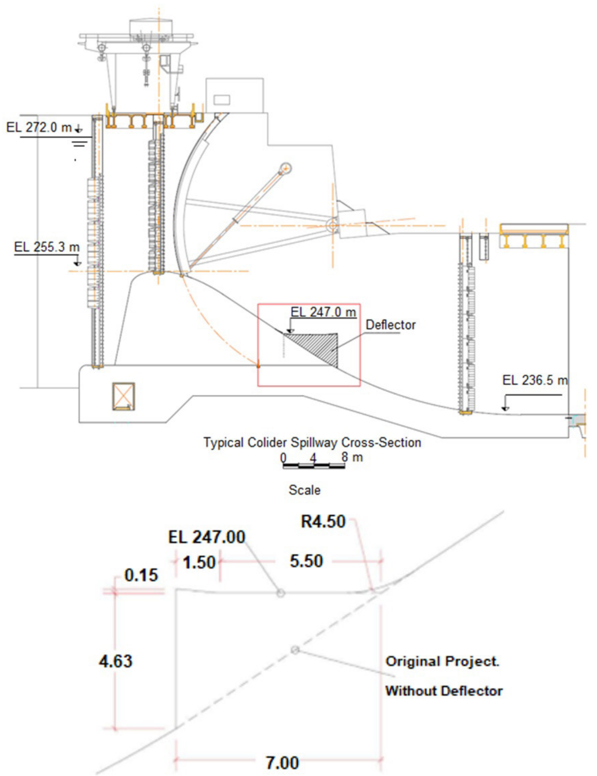

Figure 2. Colíder spillway cross-section with deflector.

Figure 3 shows jet regimes observed in the Colider spillway reduced-scale physical model developed in CEHPAR Lab (Lactec). At low TWE, water flowing over the spillway plunges deep into the stilling basin resulting in a plunging regime with the highest TDG production (Figure 3a). As the TWE increases, a skimming jet regime is observed. In skimming flow, the jet travels near the free surface minimizing the transport of bubbles to depth and considerably reducing TDG production (Figure 3b). At high TWE, a surface jump forms above the jet, aerating the downstream water surface with potential of elevated TDG production (Figure 3d). The undular flow regime is a transitional regime between a surface jump and skimming flow, the spillway jet ramps up with flow recirculation below the jet (Figure 3c). Deflectors are designed to produce a skimming flow regime over a wide range of flowrates and TWE (Wang et al., 2018).

However, the choice of the deflector geometry is not a trivial task and depends on hydraulic aspects related to the project of the plant to be studied. The crucial parameters to define the deflector geometry are length, elevation, and position relative to the downstream water levels. For design of Colider's deflector, 131 tests were performed in the physical model to obtain a dimensionless deflector performance curve.

The dimensionless plot to predict the jet regime of the Colíder deflector uses the variables indicated in Figure 4. He/hd is the ratio between water head at the deflector elevation and water head at the TWE. The deflector submergence increases

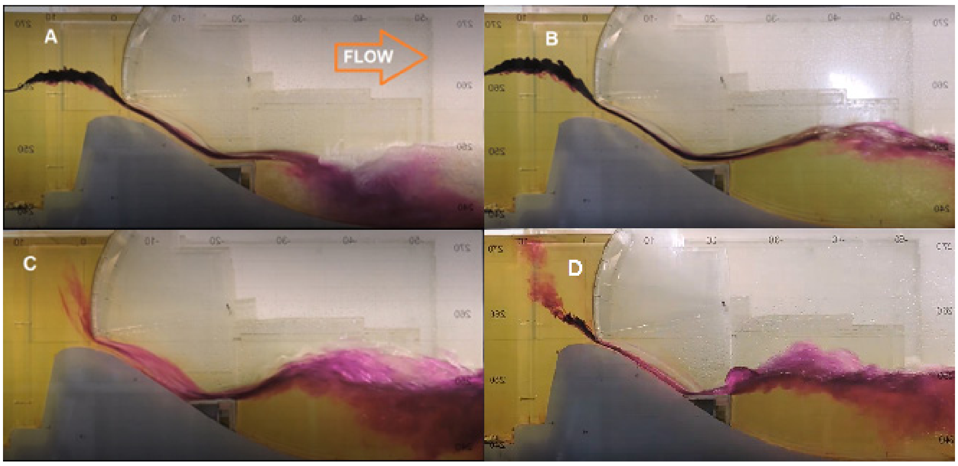

Figure 3. Jet regimes in the physical reduced-scale model: (A) Plunging flow (B) Skimming flow (C) Undular Jet (D) Surface Jump.

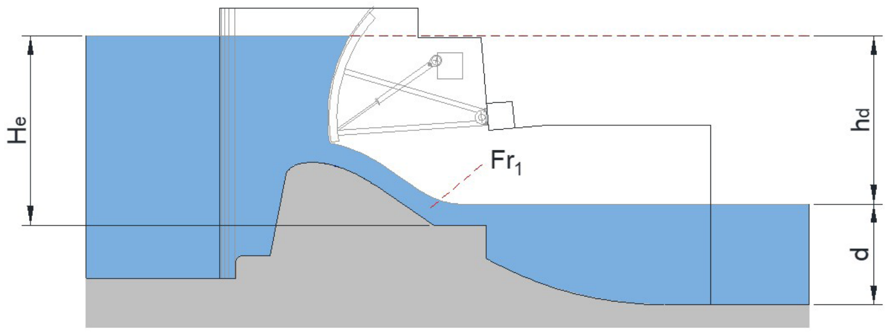

Figure 4. Variables of interest.

with He/hd. For He<hd, the deflector is above tailwater elevation and plunge pool is expected. (hd+d)/He/Fr1 relates the deflector position relative to downstream level and unit discharge. The term (hd+d)/He relates the total energy at the bottom of the stilling basin to the energy at the deflector position. Fr1 is used to consider discharge through radial gates. (hd+d)/He/Fr1 increases with the deflector elevation and unit flowrate.

Where: Fr1: Froude number in deflector apron; He: Vertical distance between reservoir water level and deflector horizontal section; hd: Vertical distance between upstream and downstream water levels; d: Water height downstream.

The dimensionless performance curve of the Colider deflector was used to select the best deflector design options (Andriolo et al., 2022). Dashed lines in Figure 5 indicate the jet regimes observed in the tests performed in the physical model. The dimensionless plot can be used to predict jet regimes in the Colíder spillway under the conditions used in the experiments and should be confirmed for other hydraulic geometries including different water heads.

NUMERICAL MODEL

Reduced-scale physical models guide the design of deflectors through the observed spillway regimes. However, since bubbles are not scaled in the laboratory, TDG production cannot be evaluated with this methodology. Furthermore, deflectors possibly perform differently in the field since bubbles and turbulence, which are not properly represented in the laboratory model, play an important role on the resulting jet regime (Politano et al., 2022a).

Numerical modeling can be very useful to understand the underlying phenomena leading to TDG supersaturation (Politano et al., 2009). A comprehensive numerical modeling analysis was completed to assess the design of the Colider deflectors using CFD (Politano et al., 2022a). This paper presents two models, based on OpenFOAM, used in this study: 1) interFoamTDG, a three-phase free-surface code to predict the hydrodynamics and total dissolved gas (TDG) distribution in the tailrace, 2) a particle tracking model to estimate possible delay in fish migration due to deflectors and TDG exposure.

The model interFoamTDG was validated against velocity data obtained in a 1:120 hydraulic model and spillway jet regimes observed in the 1:60 sectional model. The TDG module was calibrated and validated with TDG data collected in the field. Model predictions agreed well with velocity measured in the 1:120 hydraulic model under two operational conditions.

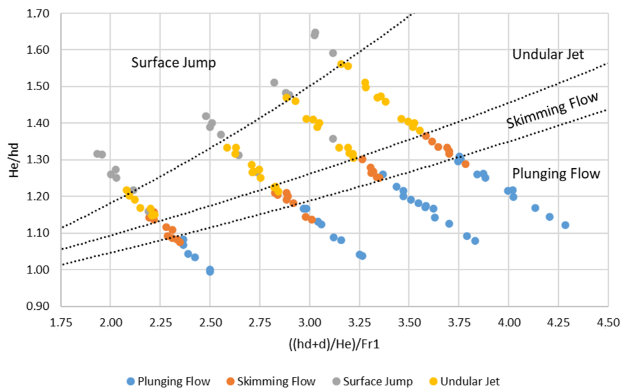

Figure 5. Dimensionless Plot to predict jet regimes at Colíder HPP (Andriolo et al., 2022).

TDG FIELD DATA

TDG probes were installed at Colider on October 3, 2019, to monitor TDG saturation upstream and downstream of the dam and to provide calibration data for the CFD model.

Conditions on January 9 and February 10, 2020 were selected to calibrate and validate the TDG model. On January 9, flowrate in spillway is 834 m^3/s, measured TDG concentration in the reservoir and tailrace were 90% and 144.8%, respectively. On February 10, flowrate in spillway is 1684 m^3/s, measured TDG concentration in the reservoir and tailrace were 105.9% and 156.4%.

CFD MODEL OVERVIEW

TDGInterFOAM represents the flow with three phases: water, air, and air bubbles in water. The model simultaneously solves the free surface characteristics, the distribution of bubbles, and TDG. The interface between air and the air/water mixture is solved with the VOF method and bubbles forming the air/water mixture are solved with a Eulerian two-phase flow model, where bubbles do not affect the liquid flow. Bubble size is predicted using a bubble number density transport equation. A scalar transport equation that includes the mass transfer between bubbles and water is used to predict TDG. Bubble velocity is calculated with an algebraic equation considering buoyancy, pressure and drag forces. The mathematical model, discretization schemes and boundary conditions of the numerical model are presented in Wang et al. (2015, 2018). The mass transfer at the free surface was neglected in the numerical model. This is because the main process responsible for TDG reduction near the dam is the absorption of gas by bubbles near the free surface, which is significantly more efficient than the mass transfer at the free surface. The model used in this study does not include an air entrainment model. Rather, the gas volume fraction and bubble size at the entrainment region are the model parameters, which were indirectly calibrated with collected TDG data.

The models used in Colider's study are based on the open-source toolbox OpenFOAM that has multiple advantages including free access, a flexible and programmable environment, and automatic parallelization. OpenFOAM solves the discrete Reynolds-Averaged Navier-Stokes (RANS) equations using a cell-centered finite volume scheme. In this study, a detached eddy simulation (DES) model was used for turbulence closure.

Two tests realized in 1:120 scale hydraulic model were selected to validate the CFD model. In Case 1, the 100-year flow event was uniformly spilled in the four Colider spillway bays. In Case 2, 50% of the 1,000-year event was spilled in bays 1 and 2. Operational conditions for these tests are described in Table 1.

Figure 6 compare the free surface predicted by the numerical model with photos taken in the laboratory for Case 1. Good agreement is found between the images and free surface characteristics predicted with the model. In this Case, all spillway gates were opened uniformly, and water flows relatively straight downstream in the stilling basin. Left and right training walls

Table 1. Conditions for CFD model validation against the 1:120 scale hydraulic model.

CFD	Spillway Bay	Case 1	Case 2
1:120 hydraulic model		**Test 1**	**Test 5**
Flowrate (m^3/s)		4,555.0	3,467.0
Spillway	1	1,138.8	1,733.5
	2	1,138.8	1,733.5
	3	1,138.8	--
	4	1,138.8	--
Gate opening (m)	1	8.506	Full open gate
	2	8.506	Full open gate
	3	8.506	--
	4	8.506	--
Tailwater elevation (m)		255.40	253.90

Table 2. Conditions for CFD model validation against the 1:60 scale hydraulic model.

CFD	Spillway Bay	Case 3	Case 4	Case 5
1:60 hydraulic model		**Plunging**	**Skimming**	**Surface jump**
Flowrate (m^3/s)		900	900	900
Spillway	1	225	225	225
	2	225	225	225
	3	225	225	225
	4	225	225	225
Gate opening (m)	1	1.11	1.11	1.11
	2	1.11	1.11	1.11
	3	1.11	1.11	1.11
	4	1.11	1.11	1.11
Tailwater elevation (m)		248.85	251.00	253.50

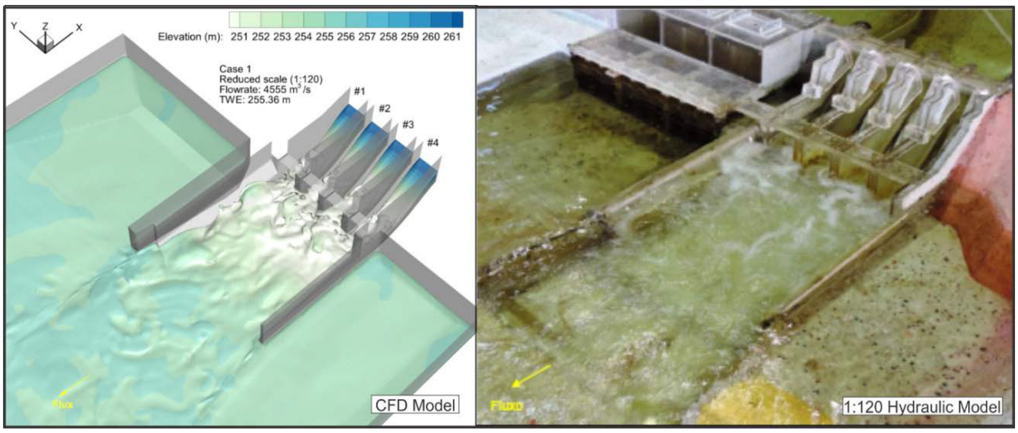

Figure 6. Free surface characteristics in the tailrace for Case 1. Top: CFD and bottom: 1:120 hydraulic model.

effectively confine the chaotic turbulent flow within the stilling basin. Noticeable wave action was observed downstream of the plunging region. However, waves significantly dampened downstream of the stilling basin.

Based on the results from the 1:60 hydraulic model, a deflector at 248 m elevation was recommended. Table 2 describes simulation conditions used to compare predicted spillway jet regimes against the regimes observed in the 1:60 scale hydraulic model (Figure 3). The model reproduced the observed plunging, skimming and surface jump regimes as shown in Figure 7.

TDG CONCENTRATION

Gas volume fraction and bubble size are experimental parameters of the TDG model. In Colider Dam, five simulations were performed to evaluate the sensibility of these two experimental

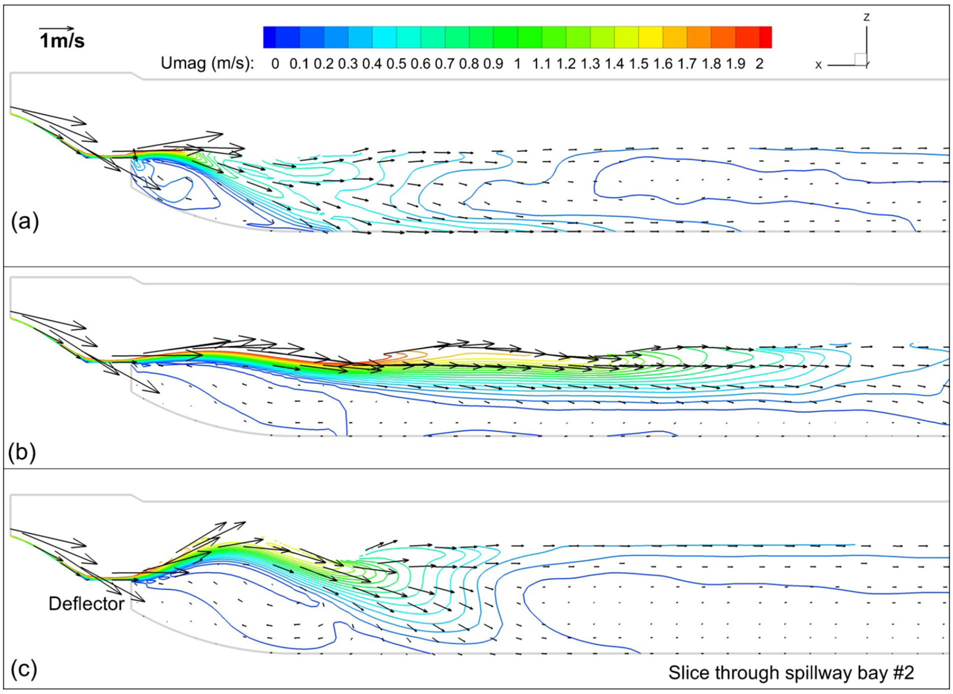

Figure 7. Spillway jet regimes. (a) plunging at TWE 248.8 m, (b) skimming at 251.0 m, and (c) surface jump at TWE 253.5 m.

parameters. Three simulations used gas volume fraction 1%, 2% and 3% with bubble diameter of 0.8 mm. Two simulations were run at a constant gas volume fraction 3% with bubble diameters 0.1 mm and 2 mm. Figure 8 shows the evolution of the average TDG at the model downstream boundary (Politano et al., 2022b).

TDG concentration is significantly smaller for larger bubbles. Larger bubbles have higher terminal velocities and reach the free surface faster and closer to the spillway before they can dissolve into water. Also, for the same gas volume fraction, the interfacial area is smaller for larger bubbles resulting in smaller TDG production. TDG concentration increases with the inlet gas volume fraction since more bubbles are available for dissolution.

The model parameters, gas volume fraction and bubble size, were selected during model calibration using TDG field data measured in the reservoir and tailrace in 2020. Model parameters used for Colider (gas volume fraction and bubble size) are consistent with similar hydroelectric projects on the Columbia River Basin, USA (Table 3, Politano et al., 2022b). The bubble diameter and gas volume fraction at the spillway gates that best fit the levels of TDG measured on January 9, 2020 were 0.8 mm and 0.03, respectively. Table 4 shows measured and predicted TDG on these days. The relative error of TDG saturation between the numerical model and the field data on January 9 and February 10, 2020 was 0.41% and 1.5%, respectively.

On January 9, 2020, the spill flow were 348 m^3/s and powerhouse flow were 610 m^3/s. On February 10, 2020, the spill flow were 610 m^3/s and powerhouse flow were 1074 m^3/s.

The highest TDG concentrations were observed in the stilling basin, due to dissolution downstream of the plunging region, where bubbles were transported to depth. On February 10, 2020, the plunging jet diffused gradually, which spread bubbles into the downstream part of the stilling basin increasing TDG concentration (see Figure 9 with TDG isosurfaces). Bubbles

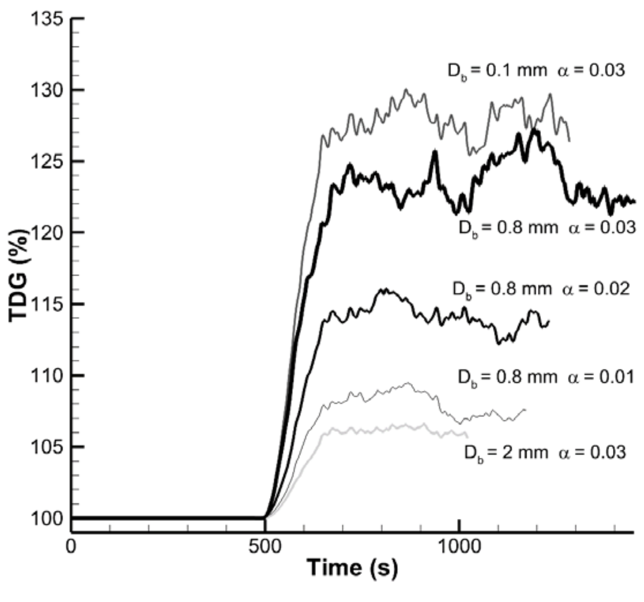

Figure 8. Average TDG at the model downstream end for the sensitivity analysis simulations.

Table 3. Model parameters used in hydroelectric projects in Columbia River Basin, USA. (Politano et al., 2022a).

	Gas volume fraction (%)	Bubble Diameter (mm)
Wanapum	4	0.8
Wells	3	0.5
Hells Canyon	3	0.8
McNary	4	0.8
Brownlee	3	0.5

Table 4. Comparison between predicted and measured TDG.

	Predicted TDF (%)	Mensured TDF (%)	Error (%)	Deviation (%)
Jan 9, 2020	145.4	144.8	0.4	0.4
Feb 10, 2020	158.2	156.4	1.1	1.5

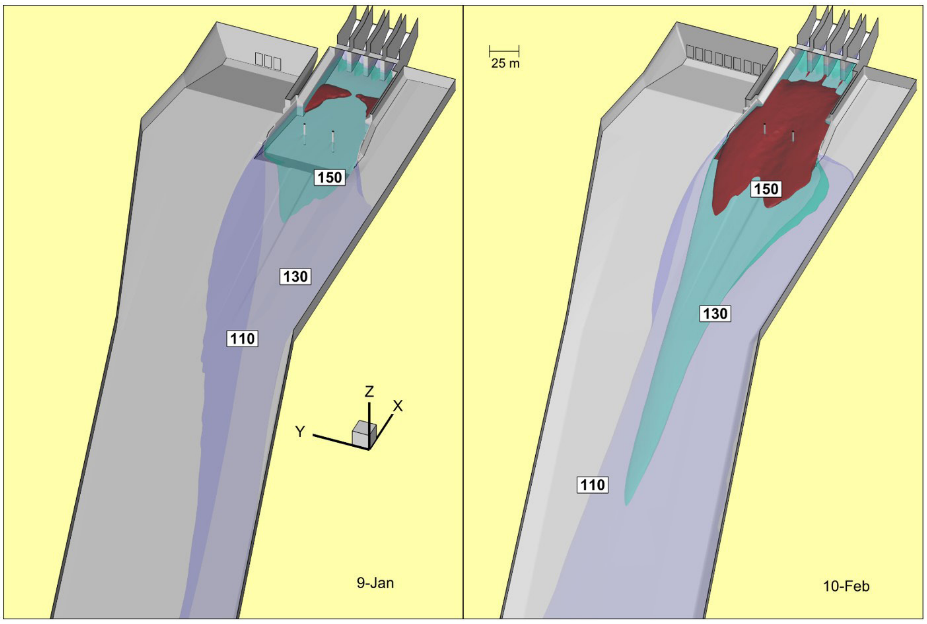

Figure 9. TDG isosurface on Jan. 9 and Feb. 10, 2020.

rapidly moved to the surface resulting in lower TDG production in the downstream channel.

TAILRACE SIMULATIONS FOR DEFLECTOR OPTIMIZATION

After the sensitivity analysis, calibration, and validation, twenty-eight simulations were performed with interFoamTDG to evaluate the effect of deflector length, curvature radius and deflector elevation on TDG uptake in the Colider tailrace. All simulations were run at the University of Iowa's hpc system and Department of Defense (DoD) hpc system (Politano et al., 2022b).

The performance curve of the spillway deflector obtained with the reduced-scale physical model was used to select a deflector and further refinement was performed with the numerical model. The performance of spillway deflectors was evaluated by analyzing production and distribution of TDG in the tailrace; flow patterns in the tailrace and potential delay in fish migration and exposure to TDG.

Two deflectors elevations (El. 247m and El. 248m) and two deflector lengths of 7m or 8m were evaluated. The river flowrates ranged from 600 m^3/s to 3,250 m^3/s, divided in three conditions of spillway flows: 600 m^3/s, 1100 m^3/s and 1637 m^3/s, and four conditions of powerhouse operation: 0 m^3/s, 533 m^3/s, 1066 m^3/s and 1600 m^3/s. Simulation conditions together with the deflector performance curve obtained in the 1:60 scale hydraulic model for a 7 m deflector length at elevation 248 m are shown in Table 5 and Figure 10.

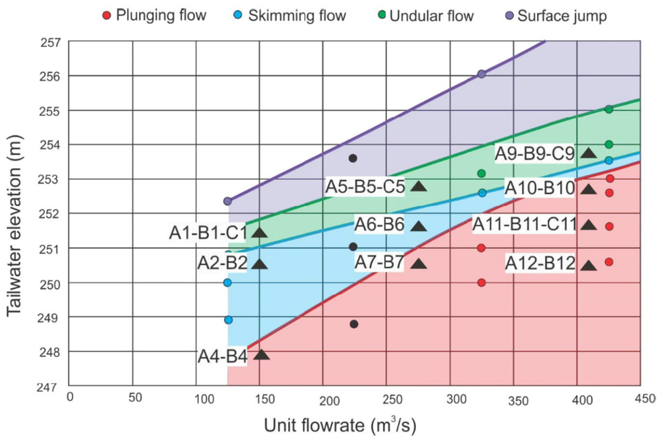

Figure 10. Simulation conditions to evaluate the deflector elevation and spillway jet regime observed in the 1:60 scale hydraulic model.

The flow pattern in the Colider tailrace is strongly influenced by the spillway and powerhouse operation. Plunging jets without powerhouse flows (simulations A4, B4, A12 and B12) transported bubbles to depth in a small region near the spillway.

Table 5 summarize the maximum TDG concentration in the tailrace and the outlet (900 m from the dam) with deflector.

Impact of TDG on fish depends on the time spent by the fish in a certain level of TDG supersaturation. To assess the potential impact on fish, 1,200 inert particles, representing fish,

Table 5. TDG at 900 m from the dam (Outlet) and maximum TDG in the tailrace.

Case	Flowrate (m^3/s)	Spillway (m^3/s)	Powerhouse (m^3/s)	Deflector elevation (m)	TWE (m)	TDG Results	
						Outlet	Maximum
A1	2200	600	1600	248	251.7	101.5	124.2
A2	1667	600	1067	248	250.5	103.8	138
A4	600	600	0	248	247.9	103	123.2
B1	2200	600	1600	247	251.7	100.9	127.9
B2	1667	600	1067	247	250.5	102.3	123.2
B4	600	600	0	247	247.9	103.8	128.7
A5	2700	1100	1600	248	252.7	110	156.6
A6	2167	1100	1067	248	251.6	111.5	161.9
A7	1633	1100	533	248	250.4	111.2	163.2
B5	2700	1100	1600	247	253.5	107.3	146.6
B6	2167	1100	1067	247	252.4	111.4	158.5
B7	1633	1100	533	247	251.2	111.2	158.5
A9	3250	1637	1613	248	253.8	118.0	183.1
A10	2704	1637	1067	248	252.7	118.6	178
A11	2170	1637	533	248	251.6	116.8	175.2
A12	1637	1637	0	248	250.4	114.5	169.6
B9	3250	1637	1613	247	253.8	117.7	177.3
B10	2704	1637	1067	247	252.7	117.2	174.7
B11	2170	1637	533	247	251.6	118.1	177.4
B12	1637	1637	0	247	250.4	115.4	172.8
A1-D07	2200	600	1600	248	251.7	101.5	124.2
B1-D09	2200	600	1600	247	251.7	100.9	127.9
D03	1477	1477	0	248 - Flat - 8m	250.3	111.8	156.1
D05	3250	1637	1613	248 - 8m	253.8	118.1	182.3
d08	2200	600	1600	248/247	251.7	101.3	129.5

were released from the spillway gates, and tracked for approximately 2,000 s with a unit spill of 150 m^3/s and for 1,000 s for unit spills of 275 m^3/s and 409.3 m^3/s. The time elapsed between the entry of a particle into the tailrace and its subsequent exit though the model outlet is the particle residence time. The exposure time refers to the total time spent by a particle in a region of a given TDG concentration. In this study, TDG concentrations larger than 110%, 120% and 130% were computed for each particle.

For the spillway operation with 600 m^3/s, decreasing the deflector elevation to 247 m reduced the exposure time to TDG > 110% from 9.2 min to 6.4 min. The lowest TDG exposure was for a deflector at elevation 247 m with all powerhouse units operating (simulation B1). The plunging is stronger for the deflector at elevation 248 m than at 247 m.

Residence time for a unit spill of 275 m^3/s (total = 1100 m^3/s) ranged from 10 to 12 min. For this operation, approximately 5% of the particles were trapped in the recirculation on the left bank. Exposure to TDG larger than 110% was between 8.2 min. to 10.8 min. Differences in exposure to TDG larger than 110% for the two deflector elevations were smaller than 1 min. TDG increases due to dissolution of bubbles entrapped in the recirculation below the jump. Some bubbles move downstream increasing TDG in the stilling basin. The downstream plunging and transport of bubbles to depth are significantly reduced for deflector elevation 247 m.

Residence time for a unit spill of 409.3 m^3/s (total =1637 m^3/s) ranged from 8 to 9 min. Most of the time particles are exposed to TDG concentrations larger than 110%, irrespective of the deflector elevation or powerhouse operation. Exposure to TDG concentrations larger than 130% was between 2.5 min. to 5.2 min. Differences in exposure to TDG larger than 110% for the different deflector elevations were smaller than 1 min.

Based on TDG production and potential TDG exposure time with the simulated deflectors and considering that most the of the time Colider Dam operates with more than one turbine, 7-meter-long deflectors at elevation 247 m was recommended for installation in the Colider Dam spillway.

Constructed of deflector

Copel concluded the construction of the deflectors in the four spillway bays in November 2021. Figure 11 shows the deflector during and after construction.

On December 15, 2021, the first spill after deflectors construction was performed. Ovelar et al. (2022), presents test results observed in prototype and compared the jet regimes previously studied in a physical model.

Figure 12 show three tests realized. Different spillway jet regimes were observed at various spill levels, A surface jump was observed in Test T1 with flowrate to 27 m^3/s in one bay. Test T4 with 87 m^3/s in one bay resulted in undular flow and a skimming flow was observed in test T7 with 153 m^3/s in one bay.

Water quality field data

Water quality probes were used to monitoring TDG saturation upstream and downstream of the dam, one located in

Figure 11. Deflector constructed into the spillway bay.

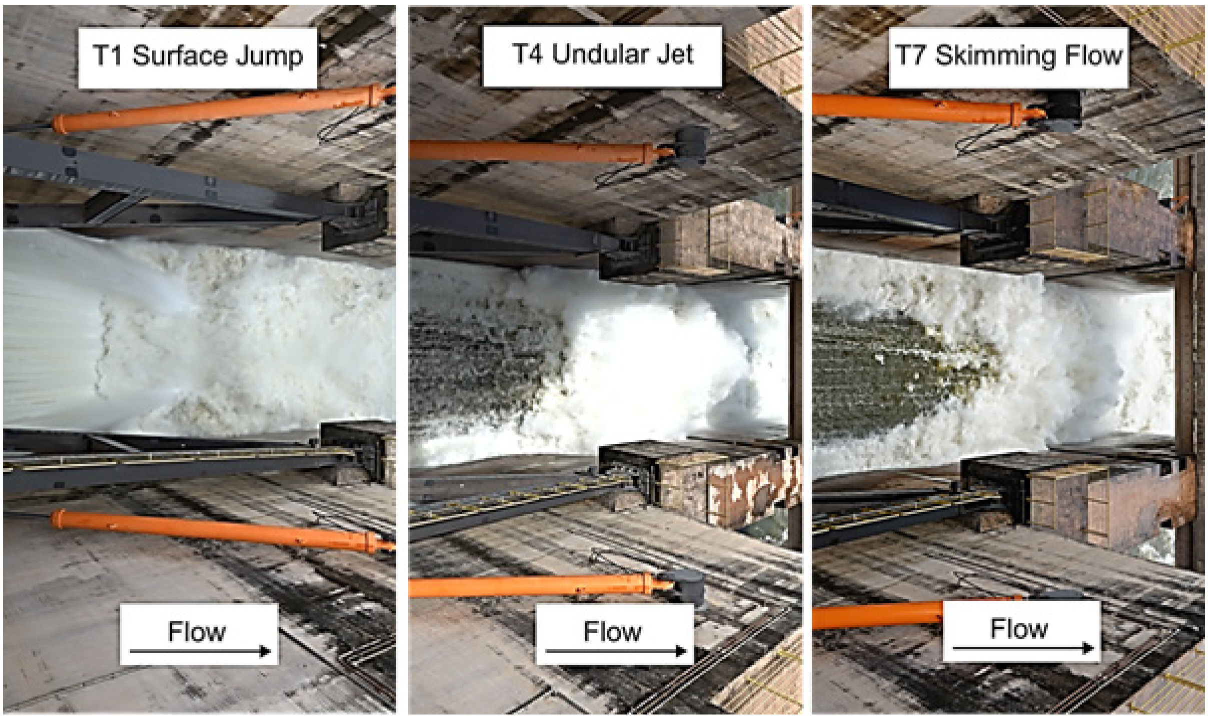

Figure 12. Spillway jet regimes – Top view of spillway bay.

the reservoir and other in stilling basin. The measures at Colider beginning in October, 2019. Before the construction of deflector, the TDG data were used to provide calibration data for the CFD model, and after to monitoring the performance of the deflector.

Figure 13 show the historical TDG data in the stilling basin of Colider during the spill events before and after the installation of deflectors. For small spill, the deflector reduced TDG by approximately 30 percentage. For spill larger than 1000 m^3/s and no operation of powerhouse, the difference in TDG is about 10 percent.

Figure 14 show the influence of the powerhouse flowrate on TDG concentration, with and without deflector. The deflector

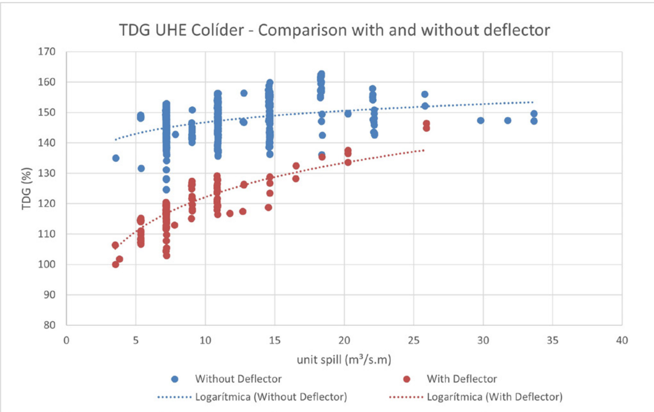

Figure 13. TDG concentration in the stilling basin with and without deflector without powerhouse flows.

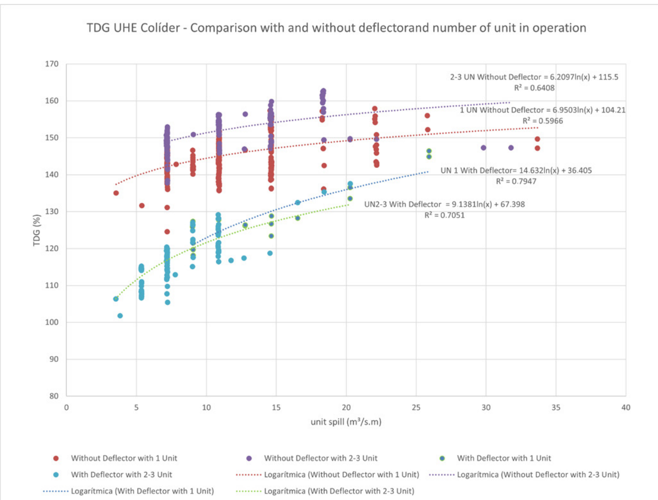

Figure 14. TDG concentration in the stilling basin with and without deflector with powerhouse flows.

reduces TDG on average by about 20 percent. For a constant spill, the TDG concentration with deflectors reduces as the turbine flow increases due to two effects: dilution by low TDG water from the powerhouse and changes in the spillway jet regime caused by increased tailwater elevation. Figure 10 shows that as the tailwater elevation increases, the type of jet regime might change from plunging flow to skimming flow or another type of regime that generates less TDG. During the deflector design process, the goal was to select a deflector that achieve the highest TDG reduction with 3 powerhouse units in simultaneous operation, which is consistent with the better deflector performance observed during high flows in the powerhouse.

CONCLUSIONS

Two study were developed to assist in the design of spillway deflectors at HPP Colider to minimize the total dissolved gas (TDG) uptake during spill events.

The first study was developed by Lactec and consisted of 131 tests in a reduced-scale hydraulic model to obtain a dimensionless deflector performance curve for HPP-Colider.

The second study, at IIHR-Hydroscience & Engineering at The University of Iowa and the US Army Engineer Research and Development Center, consisted of a TDG numerical model. After calibration and validation, twenty-eight simulations were performed to evaluate the effect of deflector length, curvature radius and elevation on TDG uptake in the Colider Dam tailrace.

Copel concluded the construction of the deflectors in the four spillway bays in November 2021. For small spill, the difference in TDG measurements due to the installation of the deflectors is approximately 30 percentage. For spill larger than 1600 m^3/s and no operation of powerhouse the difference is about 10 percent. Performance of the deflectors validates the studies carried out and shows that the solution adopted is being effective in minimizing the percentage of TDG and thus reduced the risk of ichthyofauna.

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Marcos Vinicius Andriolo: Designed the Colider's deflector. Analyzed the results of physical and numerical model and TDG's data. Elaboration of the manuscript, and project management of R&D PD-06491-0541/2019 "Metodologia para Modelagem Computacional de TDG na Água em Fluxos Efluentes de Vertedouros", developed by Lactec and Companhia Paranaense de Energia (Copel Get).

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Marcela Politano: Developed the numerical model of CFD and TDG. Analyzed the results of physical model and TDG's data.

Paulo Henrique Cabral Dettmer: Developed the physical model.

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